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THE WESTERN GRASS-STEM SAWFLY[1] A PEST OF SMALL GRAINS

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INTRODUCTION

The western grass-stem sawfly (*Cephus cinctus* Norton) (fig. 1) is in many ways one of the most interesting and important insects that has attracted the special attention of the economic entomologists in the last 20 years. It is a species native to the United States and has been gradually coming into prominence since the beginning of the present century by reason of the change in its larval feeding habits since its discovery. Originally a grass feeder, it is becoming a serious menace in the Northwestern States because of its acquired appetite for small grains, within the stems of which it now subsists.

Such changes of diet are probably occurring everywhere with greater frequency than formerly was deemed possible, especially among the phytophagous insects of the Middle West. When given a chance to feed upon the various cultivated plants grown in bulk by the farmer or gardener, many of these insects gradually desert their native host plants and to a greater or less degree change their habits, including in their fare the more succulent and easily found food.

HISTORY

The existence of the western grass-stem sawfly was first made known in 1890 when Albert Koebele reared adults from larvae that were mining in the stems of native grass growing in the vicinity of Alameda, Calif.[2] In 1891 the species was described under the

[1] This bulletin is a revision of and supersedes Department Bulletin No. 841, The Western Grass-Stem Sawfly, issued May 7, 1920.

[2] KOEBELE, A. CALIFORNIA NOTES. U. S. Dept. Agr., Div. Ent. Insect Life 3: 71, 1891.

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name of *Cephus occidentalis* by Riley and Marlatt,[3] from a series of individuals reared by Mr. Koebele and also from cotypes that had in the meantime been collected in Nevada and Montana. In connection with this description the following prophetic suggestion was made:

> The economic importance of this species arises from the fact that it may be expected at any time to abandon its natural food-plant in favor of small grains, on which it can doubtless successfully develop.

Nothing more was heard of this sawfly until 1895, when James Fletcher, then entomologist of the Dominion of Canada, swept adults at Indian Head, Northwest Territories, on July 5. He believed it to belong to the European species *Cephus pygmaeus L.*, and under this name it was mentioned in his report for 1896[4] with the further

FIGURE 1.—Adult female of western grass-stem sawfly (*Cephus cinctus*). Enlarged to about 4½ or 5 diameters

statement that wheat straws containing Cephus larvae had been sent in by John Wenman, of Souris, Manitoba, who stated that the injury done by them was very slight. Nevertheless the prophecy of five years before had been fulfilled, since these grass feeders actually had attacked small grain.

In 1902 Fletcher reported, in a personal letter, that he had found the larvae numerous in grasses in the Northwest. In 1905 and 1906 G. I. Reeves, of the Bureau of Entomology, noted the work of the larvae in various grasses, chiefly *Agropyron* sp., in Wyoming and the Dakotas, and in 1906 the same observer found the larvae attacking wheat sparingly near Kulm, N. Dak.

On August 31, 1907, E. G. Kelly noted a few wheat straws near Minot, N. Dak., that had been burrowed by the larvae of Cephus.

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[3] RILEY, C. V., and MARLATT, C. L. WHEAT AND GRASS SAWFLIES. U. S. Dept. Agr., Div. Ent. Insect Life 4: 177–178, illus., 1892.

[4] FLETCHER, J. REPORT OF THE ENTOMOLOGIST AND BOTANIST. Canada Expt. Farms Rpt. 1896: 229–230, illus. 1897.

In 1908 F. M. Webster and G. I. Reeves found the larvae of Cephus working in grasses in the Willamette Valley in Oregon. In the same year Fletcher again called attention to this insect, stating that in the previous fall it had appeared in central Manitoba and in the southeastern part of Saskatchewan in much more serious numbers than ever before, and that the quantity of broken straws in the fields was causing the farmers some alarm. Norman Criddle of Aweme, Manitoba, a close observer and practical farmer, wrote to Fletcher that this fly had increased considerably during the last year or two, and was turning its attention to wheat and rye.

On August 20, 1909, H. B. Penhallow reported from Sherwood, N. Dak., that he had examined about a hundred fields from Minot, N. Dak., north to the boundary line and several miles into Canada and had found larvae present in every field but one. He estimated the damage in these fields as ranging from 5 to 25 per cent of the

FIGURE 2.—Distribution of the western grass-stem sawfly in the United States

crop, but spoke of one field about 27 miles east of Sherwood where the damage was said to have exceeded 66 per cent. R. W. Sharpe reported similar damage in the Red River Valley, near Fargo, N. Dak.

During 1911 and 1912 the writer found the species occurring freely in the native grasses in various parts of Utah, and, as occasion offered, the life history of Cephus was learned. Many of the facts in this bulletin are the result of this study. (Fig. 3.)

During the years 1913, 1914, and 1915 the writer found this sawfly almost universally distributed over the Dakotas, Minnesota, Iowa, and Nebraska. It was feeding in Elymus, timothy, and Agropyron at Elk Point, S. Dak., in *Agropyron tenerum* near Chamberlain, S. Dak., in timothy at Edgeley, N. Dak., in *Bromus inermis* near Merricourt, N. Dak., in *Elymus canadensis* at Shakopee, Minn., in practically all these grasses near Sioux City, Iowa, and in wheat, timothy, and Elymus near Minot, N. Dak.

FIGURE 3.—Plants of *Elymus condensatus* growing along the railroad right of way, the natural habitat of the western grass-stem sawfly in Utah

FIGURE 4.—Wheatfield of Thomas Yeam, near Souris, N. Dak., showing heavy damage done by the western grass-stem sawfly in 1916

This insect seems to have little choice in the various native grasses and is ready to attack any of the cultivated sorts provided the stem is sufficiently large for the larval gallery. As a rule, the larger, more robust stems are chosen for attack, especially in cultivated grasses such as timothy and Bromus. Bluegrass and similar slender-stemmed species appear to be immune. *Stipa viridula* from northern New Mexico, a robust grass growing in almost the same latitude as the *Elymus condensatus* near Pinto, Utah, where the fly abounds, was not found infested.

August 25, 1916, the writer, then at Pierre, S. Dak., received instructions from the Bureau of Entomology to visit Bottineau County

FIGURE 5.—Bird's-eye view of wheat in Thomas Yeam's field, near Souris, N. Dak. Ninety per cent of these fallen wheat stems have been mined by the western grass-stem sawfly

in North Dakota and investigate injury to wheat. It was believed locally that the Hessian fly was responsible for the damage that was being done. A very superficial examination of the injured fields proved beyond a doubt that the Cephus was present in large numbers and was doing an immense amount of mischief. Every field visited was infested, not only in Bottineau County, but in the adjoining counties of Benson, Pierce, McHenry, and Rolette. Near Souris, a few miles south of the Canada line, a large field of wheat on the farm of Thomas Yeam was fairly carpeted with the "straw-fallen" grain. (Figs. 4 and 5.) The loss from injury by Cephus in this field was estimated at 60 per cent or more. Six feet of drill row here was taken at random and examined plant by plant. Forty-eight infested stubs were found, an average of eight to each foot of

drill row. This would mean 150 to the square yard or about 726,000 larvae to the acre. Higher counts were made later in the same field, so the average may be larger than stated. During April, 1917, Mr. Yeam's field was again visited and a random square yard marked out and counted. Two hundred and sixty-nine infested stubs were taken from this yard, which would mean more than 1,300,000 larvae to the acre. Fifty of these stubs were opened and 47 of the imprisoned larvae that had spent the winter within the straw were found to be normal and very much alive. The proportion of living individuals among the hibernating larvae seldom falls below this ratio.

In the spring of 1917 the dry weather in this district hindered the growth of both grasses and grains, so when the adult Cephus began to appear in June there was almost no opportunity for oviposition. Stems of Bromus from chance sods growing among wheat and on waste ground were filled with eggs. Young plants of spring wheat that had barely begun to joint were attacked and often contained as many as three and four eggs placed in the stem close to the ground. With a few strokes of the net 136 adults were swept from young wheat, so numerous were the flies at that time. In spite of the unfavorable oviposition conditions of that spring, the eggs appear to have hatched, and at harvest time the majority of the wheat stems had been bored and many were cut off at the base. Careful harvesting and the use of horserakes saved a large portion of what otherwise would have been a total loss. The infestation was much more general than in 1916.

A somewhat hasty reconnaissance was made through north-central North Dakota in August, 1919, that it might be ascertained as definitely as possible just how the attack of Cephus was progressing. A number of fields in Bottineau County were examined and found to be heavily infested. Most of these had been raked after harvest, and it was consequently impossible to compute accurately the percentage of infestation. The numerous sawfly inhabited stubs in the drill rows, however, proved the severity of the attack. It was roughly, though conservatively, estimated that about 30 per cent of the grain had gone down in most of these fields as the result of Cephus work.

It was conceded by many observers in that region that the injury during the year 1919 was greater than during any previous year since the study of this pest was begun. More fields had been seriously invaded and were injured to a larger extent than had before been observed. Even fields of durum wheat, hitherto believed to be nearly free from fly attack, were said to have been severely injured in 1919.

It may be stated, however, that the farmers are profiting by past experience and have used horserakes to gather the fallen grain in stubble fields to such an extent that the percentage of actual loss of grain has been reduced to a small figure. The quality of grain from the fallen straw is naturally somewhat below the normal, since the work of the larvae in the stems produces some injury in the heads as they fill.

Cephus was found mining wheat near Hettinger in southwestern North Dakota, July 18, 1917. On September 22, 1917, infested wheat was found near Mott, 30 miles north of Hettinger. In October of

the same year many wheatfields in Towner and Cavalier Counties, in northeastern North Dakota, showed heavy infestation, although during the previous year it was difficult to discover more than a trace of the presence of Cephus in the wheat in this region.

Sods of *Elymus canadensis* sent to the writer from Charleston, Mo., in the summer of 1917 contained at least one larva of *Cephus cinctus* that had been boring the stem of this grass in that region.

From the map (fig. 2) and foregoing brief summary of its history it may be seen that *Cephus cinctus* is distributed over an immense territory and that it constitutes a potential menace to the small grains throughout this vast region. As the acreage of native grasses is decreased from year to year by the bringing of wild lands under the plow, pests such as the sawfly will be forced to depend in an increasingly large measure upon the small grains and other products of the farms. On this account the injury caused by these formerly harmless insects bids fair to increase steadily. In the past the numbers of grass-feeding insects such as the one considered in this bulletin have been governed mainly by the supply of food plants. A dry summer that retarded the growth of long-stemmed grasses would automatically reduce the numbers of the insects that lived within these grass stems. It is easy to see how seasonal fluctuations in vegetation would, to a large extent, react either to multiply or diminish the numbers of these insects. Cephus seems to defy the drought.

Then again, the farmer, by introducing fields of grain into a region previously uncultivated, brings in conditions unknown before and invites the attack of these and other formerly harmless insects, making it possible for them to become a menace to his future.

A somewhat similar sawfly of European origin[6] was discovered in 1918 to have become established on wheat along the Atlantic seaboard from Long Island southward to northern Virginia.

FOOD PLANTS

The various species of Agropyron and Elymus, genera both of which are well represented in the West, appear to have been the original hosts of the larvae. Since the feeding habits of the insect have been modified by changing agricultural conditions, the list of their present host plants, so far as known, stands as follows:

Elymus canadensis.	*Agropyron occidentale.*	*Calamagrostis* spp.
Elymus condensatus.	*Agropyron caninum.*	*Festuca* sp.
Agropyron tenerum	*Hordeum jubatum.*	Wheat.
Agropyron richardsoni.	*Bromus inermis.*	Barley.
Agropyron smithii.	*Phleum pratense.*	Spelt.
Agropyron repens.	*Deschapsia* sp.	Rye.

Since the larva is wholly unable to move from one stem to another, it is very obvious that the host stem must be large enough to afford both shelter and food during its entire growing period. Hence only the larger-stemmed grasses can serve as host plants for the Cephus larvae. Occasionally an unusually vigorous plant of a slender-

[6] *Trachelus tabidus* (Fab.). See the following publication: GAHAN, A. B., BLACK GRAIN-STEM SAWFLY OF EUROPE IN THE UNITED STATES. U. S. Dept. Agr. Bul. 854, 18 p., illus. 1920.

stemmed grass, like *Hordeum jubatum*, affords stalks with diameter sufficiently great to be attacked by Cephus.

Small grains, such as wheat and rye, readily serve as hosts to this insect, because they are of suitable size and the length of their growing season coincides with the growth of the larva. Even if harvest time should happen to come before the maturity of the larva, the reaping machine probably would sever the stem far enough above the ground to leave the larva below the sickle cut, where it could house itself safely before the end of the season.

DISTRIBUTION

Up to the present time this species has confined itself almost entirely to the West and has been found in only a few localities east of the Mississippi River, namely, in Wisconsin and Michigan. West of the Mississippi River it has been recorded from Minnesota, Iowa, Missouri, North Dakota, South Dakota, Nebraska, Montana, Wyoming, Colorado, Utah, Nevada, Oregon, and California. Its choice of wheat for food has taken place, so far as known, only in North Dakota, Montana, and western Canada.

THE EGG

The egg of *Cephus cinctus* is, when newly laid, decidedly crescent-shaped, glassy in appearance, milky white, usually quite symmetrical, the ends of the crescent tapering and rounded. It is marked by very faint, short, longitudinal lines or wrinkles, placed without regard to order or pattern.

The size of the egg varies with the size of the female that produced it and measures from 1 to 1.25 mm. in length. The greatest breadth is about one-third the length.

The covering membrane is hyaline and transparent. Although very thin and delicate it is strong enough for the egg to be safely lifted and moved by the aid of a fine brush. The egg always lies free within the stem of the host plant, either in the stem cavity or in a hollow excavated by the ovipositor of the female. This cell is always a little larger than the egg, so it is comparatively an easy matter to remove the egg to a moist cell or elsewhere for study.

The number of eggs laid by each female appears to vary but little. Dissections of a number of adults taken in the field and of others reared in captivity agree in most cases in giving a count of about 50 eggs in the ovaries, these eggs being, as a rule, equal in size and apparent maturity.

After a number of trials it was found to be impracticable to rear the egg in situ, since it was next to impossible to maintain the proper moisture conditions within the stem. The method that was finally adopted, and that gave excellent results, was to remove the egg from the stem and place it in a minute drop of water within a small thin watch glass which was then immediately inverted on a glass slip and sealed with a ring of water to prevent undue evaporation. This form of moist cell proved quite satisfactory and permitted continuous examination of the egg with a moderately high-power lens during the entire period of incubation. It was found necessary, in order to conserve the requisite moisture supply during a period of several

days, to invert over the sealed cell a larger watch glass and over this in turn a tumbler. In this manner evaporation was reduced to a minimum. It is altogether probable that the quantity of moisture in such a protected cell exceeded that normally present within the grass stem, but in every egg treated in this way the development appeared to progress naturally.

Temperature and moisture are the prime factors that hasten or retard egg development. The temperature maintained within the laboratory during the course of these investigations was much more equable than that in the field, where, as in Utah, the heat of the sun through the daytime, and the chilly night following, must alternately hasten and check development. The data given below, therefore, may only approximate what is actually found under field conditions.

A few hours after the egg leaves the oviduct the milky-white contents of the egg, which at first completely fill the envelope, shrink a little from each end, leaving a transparent space or vacuole. After the first day the egg changes shape, becomes intumescent, generally loses its crescent shape entirely, and grows oval or reniform in outline. Gradually the interior mass of exceedingly minute particles coalesces until about the second day when a series of faintly discernible cells arranging themselves along a central axis begins to appear. Early on the third day the form of the larva can be dimly seen, the head being almost transparent and filling one end of the egg sac. The body is looped on itself, the cauda folded beneath the abdomen and extending forward nearly to the head. By the close of the third day the abdominal segments are usually well defined.

During the fourth day, in most cases, a spasmodic and intermittent heart beat may be noticed. These pulsations become more and more regular as the hours pass, and during the fifth and sixth days the heart beats with much regularity at the rate of about 120 impulses per minute. At intervals it may be retarded to 75 beats, but it soon resumes its former rate.

The head appears disproportionately large at this time, but although its general outlines are well defined the mandibles and eye spots are not yet visible. Overnight, at the close of the fifth day, the mandibles turn brown and the eye spots appear and darken. Usually after the fourth day the muscular system of the larva is in almost constant motion, shifting and adjusting, with the heart pulsating and the muscles moving, all clearly to be seen through the transparent membrane that serves as the shell.

The activity of the larva within the sac increases during the sixth day and either on this day or the seventh it escapes from its confinement by a series of convulsive movements that rupture the delicate shell and set it free.

THE LARVA

When it escapes from the egg the larva (fig. 6) possesses a very large head armed with a pair of powerful biting jaws and has a vigorous appetite. It is very active from the start and begins almost at once to feed upon the living parenchymatous tissue by which it is surrounded in the interior of the stem, excavating for itself a threadlike gallery both above and below the cavity where the egg formerly lay.

The larva is nearly transparent and colorless until it become filled with the tissue on which it subsists.

The body segments are strongly and clearly marked from the time the larva leaves the egg. The mandibles are brown, three or four pointed, the points chisel-shaped, beveled on the inside edge. The brown face plate is filled with crossed bands of striated muscular fiber that actuate the powerful jaws. The caudal horn, by means of which the larva moves up and down in its gallery, is also brown and is armed, even in the first instar, with a series of stout bristles at the base of its cylindrical and squarely truncate extremity. The larva is footless, the position of the legs being marked by minute, rounded tubercles terminating in a few short bristles.

Although the primary excavation made by the larva may extend for a short distance above the egg cell, the general course of the progress is invariably downward. In its earlier stages of existence, at least, the larva traverses its gallery several times, swallowing repeatedly the same fragments of tissue that have already been devoured during the first excavation of the stem. Young larvae are frequently found several inches above the lower end of the boring, moving through the solidly packed "sawdust." As the larva approaches maturity it is doubtful if it ventures into the upper and slender part of the stem, but it reworks the frass farther down, enlarging the bore in places.

FIGURE 6.—Newly hatched larva of western grass-stem sawfly. Enlarged about 20 diameters

The number of instars is difficult to determine, owing to the larval practice, just referred to, of passing all the frass several times through the digestive apparatus. Nearly all of the cast skins disappear completely under this treatment, only the heavily chitinized parts such as the mandibles and caudal horn being recognizable in the burrow. Careful investigation of these fragmentary remains indicates that there are four or more molts. The contents of innumerable stems have been examined with scrupulous care and with varying results. In a few cases as many as four sets of mandibles and in others four caudal horns have been found, mixed with the frass within the stems. Seldom were more than four sets removed from a single stem; usually only three were found. As is stated elsewhere in this bulletin, it is no uncommon thing to discover two and even three larvae mining a single stem, although only a single individual can possibly reach maturity with the quantity of nutriment contained in one stem. It is believed that the larva that finally reaches maturity has devoured its rivals. It is obvious that the remains of these superfluous individuals would naturally be counted when a census of exuviae was undertaken and would complicate the result. But from the best evidence obtainable it is almost certain that there are five instars in the larval life of this species.

The length of the larval period is probably about 60 days, varying more or less with the warmth of the summer and the state of maturity

of the host stems. Any change of the oviposition period due to an early or late spring has much to do with the date of maturity of the larvae, and possibly with the length of the larval period. On August 29, 1911, at Kimballs, Utah, at an elevation of 7,000 feet, the writer found mature larvae in the stems of *Elymus condensatus*. The next year, at the same place, oviposition was beginning freely in the first week of July. The determination of the larval period is wholly inferential, based upon the findings in a series of stems. (Figs. 7 and 8.)

FIGURE 7.—Mature larvae of western grass-stem sawfly removed from their galleries. Enlarged 4 diameters.

The full-grown larvae vary greatly in size, their growth being governed, as is usual in the case of such borers, by the quality and quantity of food consumed. Those living in wheat stems are much smaller as a rule than those found in rank-growing grasses such as Elymus. Measurements of a series of individuals give a range of from 8 to 14 millimeters in length and 1 to 2 millimeters in diameter.

FIGURE 8.—Mature larva of western grass-stem sawfly. Enlarged 8 diameters.

When mature the larva always seeks the extreme base of the stem, where it begins its preparations for hibernation. Its first move is to cut a neat V-shaped groove entirely around and inside the stem, usually at or a little above ground level. This groove never severs the stem completely, but so weakens it that the upper stalk, swayed by the wind, will break off completely when dry, leaving a stub that is very characteristic of the work of this insect. (Fig. 9.) In this simple manner the larva provides for the easy escape of the adult from the stub in the following summer. The length of the stub thus formed varies greatly. In *Elymus condensatus* it sometimes will project above the ground as much as 3 or 4 inches, while in other grasses, and

especially in wheat, stubs can often be found less than an inch in total length.

Instances have been observed where two or more grooves had been cut inside the same stem, as if the larva had been uncertain as to the best place for severing the stem. After cutting its characteristic groove within the stem the larva forms a mass of the debris into the hole just below the groove and in this manner plugs the upper end of the stub that is to be left in the ground after the upper stalk has been broken away. (Figs. 9, 10, and 11.) This dry frass is packed firmly into its place, perhaps by means of pressure rather than by being cemented with a liquid furnished by the larva, since the plug is readily penetrated by moisture. This statement is somewhat remarkable in view of the fact that so large quantity of moisture

Fig. 11.—Wheat stubs from fourteen days' [illegible] with the second generation nearly

appears to have a deleterious effect upon the spring larva. One would suppose that these stubs, often wholly submerged in water-soaked earth for weeks at a time, would absorb, during the long period of hibernation, a fatal quantity of dampness from the rain or melting snow. There is more or less winter fatality and some of this may be due to moisture penetrating the stub.

On September 16, 1911, one of the larvæ was removed from the hibernation chamber and placed in a small vial, still inclosed within the silken tube or cocoon, which was unbroken. For months this larva remained motionless except when the vial was exposed to bright sunshine, when, because of the light or heat, or both, it would become active at once, and crawl up and down within its cocoon in its efforts to escape. On January 20, 1912, to prevent the air in the vial from becoming too dry a small drop of water was introduced

and the vial again sealed tightly. An hour later it was noticed that the silk tube had collapsed and that the larva within was limp and apparently dying. The surplus moisture was removed quickly, whereupon the larva revived almost at once. If the same quantity of moisture had entered the stem where the larva was living it probably would have caused its death. This experiment, taken in connection with others that were not so fatally conclusive, seems to prove that the pocket plug in the stalk must in some way prevent the admission of an undue quantity of moisture into the chamber below, although water readily penetrates it.

The gallery below the plug is always entirely free from debris, forming a hibernation chamber and later a pupation cell. Within this chamber the larva lies with its head up and usually pressed against the barrier at the top, always on the alert to retreat downward at any sign of disturbance. It descends by alternately flexing and straightening the body, bracing itself first by the jaws, then by the caudal horn as it hitches its way down. In ascending, the caudal horn is thrust against the side of the gallery or the cocoon, the body is straightened, the jaws obtain a purchase to hold the distance gained, whereupon the body is again drawn up until the caudal horn is applied to the side wall for another push.

Fig. 2.—[illegible] sawfly, enlarged 3 diameters, the two left-hand ones [illegible]

Late in the summer or in the fall the larva spins for itself within the hibernation chamber an almost transparent tube of fibrous tissue. This silk tube is sometimes several times the length of the larva, is closed at both ends, and is free from the sides of the chamber, so it can often be readily withdrawn entire. When first constructed this fabric is comparatively strong and pliant but after some months it grows more brittle and is easily ruptured. As a rule it remains intact until the emergence of the adult. Even the presence of a half score of parasitic larvae often fails to wreck the delicate structure during the winter.

The longevity of the sawfly larvae is remarkable and is worthy of mention. On September 8, 1911, a number of culms of *Elymus canadensis* containing Cephus larvae were gathered and set upright in and within doors. From time to time this sand was moistened but

finally was allowed to stand perfectly dry. During October, 1912, these stubs were examined and a number of the enclosed larvæ were found to be still living, active, and unchanged. Four months later, 17 months from the time they were gathered, they were still alive and feebly active. Infested stubs of the same grass taken during September, 1912, and treated in the same manner contained at least one living larvæ on February 23, 1916, three years and five months later. The others had nearly all died within about 30 months from the time they were gathered. It is possible that the lack of necessary moisture may account for the retardation of these captives. The same retardation of development, however, has been noted in the field. Inhabited stubs of the previous year's growth of grass and grain not infrequently have been found which contain larvæ that seem to all appearances entirely normal and active. It appears more than probable that in this manner the perpetuation of the species is assured in case of unfavorable seasons.

FIGURE 11.—Stubs of wheat severed normally by larvæ of the western grass-stem sawfly

During the winter the larvæ are, of course, frozen, or are chilled into immobility and show no signs of life when disturbed. As soon as the earth warms in the spring they again grow active and move freely up and down within the limits of the silk-lined hibernation chamber until the time of pupation arrives.

THE PUPA

The pupa when first formed is milk white, slender, and somewhat longer than the larva from which it was derived. Its average length is not far from 12 millimeters and its breadth is about 1.5 millimeters. The pupa (fig. 12) lies motionless within the silken pupation chamber or cocoon for probably a day or two, after which it again becomes active. When disturbed it will endeavor to escape the threatened danger by moving either up or down the tube, hitching itself along in much the same manner as the larva but going a lesser distance with each effort. Like the larva it is almost always found with its head pressed closely against the plug of frass at the upper end of the chamber. In a few cases pupæ have been discovered heading downward in the stem. It is doubtful if these can reverse

FIGURE 12.—Pupa of western grass-stem sawfly, enlarged

their position, but the adults which issue are probably agile enough to turn about and escape.

The duration of the pupal period is not known certainly, but is believed to be very brief, not more than a week at the most. After the first day the legs and body darken until they become a lustrous black within the transparent, almost invisible, filmy membrane in which they are inclosed. This membrane is often broken and may occasionally be destroyed by the movements of the pupa within the chamber.

When fully mature the pupa changes within the cell to an active adult. The adult remains for a longer or shorter time in the cell before forcing its way upward through the plug or frass, placed at the upper end of the chamber by the larva now nearly full grown, and emerging. The writer, by splitting stalks of grass or grain in June, has repeatedly liberated adults, which, when free, were able to take instantly to wing without any preliminary drying or other preparation.

A very few die within the cell, possibly because of lack of energy needed to break through the stopper of frass above them. In cases where the girdling of the stem is inefficiently done, so that the grass stalk did not break off during the winter season, the adult does as a matter of course, since these flies are not fitted with mandibles capable of biting through the woody stems of dry grass.

THE ADULT AND ITS HABITS

The adult *Cephus cinctus* is a beautiful insect with a polished black body marked by three prominent yellow bands across the abdomen. The legs are yellow and the wings smoke colored.

The description by S. A. Rohwer follows.

Length 7 to 12 mm. Head shining, polished; anterior margin of clypeus truncate with sinuate prominent and sometimes silvery pubescent; mandibles rufous; antennæ black; flagellum with approximate joints 10 to 16 shorter than the scape; thorax shining but with appressed pubescence on scutum; scutum coarsely punctured but a little smaller at base; scutellum with two rows rounded; hypopygium rather broadly emarginate apically; femora marked with bright yellow, amount and extent of yellow markings very variable, ranging greatly; basal of female usually black but more rarely with two narrow yellow or having yellow spots; basal of male black but always with yellow on face; thorax black, the upper angle of metapleurum, parapteræ, and sometimes (usually) tegulæ yellow; legs yellow with some blackish; (occasionally both of these having yellow marks); basal of tergum three or two pairs of yellow spots sometimes black; last three segments usually yellow; abdomen black; last three segments usually yellow; abdomen black; apex of basal or second tergite, basal or third, and sometimes fourth, apex or basal or second tergite, basal or third, and sometimes fourth, tergites and lateral margins of tergites yellow, the apex and extent of these markings varying and occasionally the fourth tergite having a yellow band; wings subhyaline; venation dark brown, costa and stigma yellow.

The female is noticeably larger than the male and is less active.

The characteristic attitude of the adults of either sex while at rest during the chill of the morning and after sundown is lying flat against the grass stem, head downward, the legs not spread but overlaid in line with the body which is concealed behind the closely folded, smoke-colored wings. The ease with which such a strikingly colored fly, while in this position, can escape observation, is remarkable. The fly looks in the sun at midday, on the warm side of grass stems, with the wings partly spread and the legs unextended. Like most Hymenoptera, this species is very partial to sunshine and rarely

is seen abroad on a cloudy day. In fact, it is not then easy to find these flies at all, unless one is entirely familiar with their habits.

They are weak fliers and seldom travel to any great distance at one time. In Utah they commonly move about among the plants of bunch grass, making short flights from tuft to tuft. If the wind rises or the sun goes behind a cloud they promptly disappear until conditions again become satisfactory. The writer has never taken the adults at any great distance from their breeding places.

Their hovering flight is peculiar, the swaying motion of their bodies in the air reminding one of certain tipulid flies during their mating-air dance. They often hover for a long time to the windward of a grass plant without alighting. The males are on the wing much more than the females. The adults are not at all tame and can often be readily taken from the grass stems with the fingers. When conditions are favorable the female is usually too intent on oviposition to be easily annoyed but if disturbed beyond endurance she quickly disappears, her dark color and slender body enabling her to vanish completely among the vegetation.

Copulation is very brief, usually lasting less than a minute.

The species is single brooded, the adults appearing during the spring and dying some time about midsummer.

The earliest individual met in Utah was taken in a net April 26, 1910, in an alfalfa field. Adults have been seen in the mountains late in July, and they probably linger longer than that, ovipositing in such green grass stems as they can find. Near Kimballs, in Utah, September 8, 1911, the writer took very young larvæ from stems of *Elymus cinereus*, growing from plants that had been browsed by cattle and had thrown up fresh green stalks.

Norman Criddle states that in Canada the adults appear during the second week in June and may be met with until about July 10. Occasionally they may be found feeding on flowers. Fletcher took them in Canada on flowers of the tumbling mustard. The time of their appearance and the length of adult life are both largely governed by climatic influences and vary with the season.

When confined in emergence tubes or other limited places the males attack one another without mercy, using their jaws freely to snip off the antennæ and, in some cases, the legs of their rivals. Singularly, very few of the females confined with them are thus mutilated.

OVIPOSITION

Weather conditions are always an important factor in controlling the oviposition of insects and they are of particular importance in the case of the Cephus. Only on bright, warm, still days are they to be found busy placing their eggs. In Utah, where the first studies of their habits were made, the mornings and evenings are chilly as a rule, hence the activity of these flies is confined to the hours near midday. They are usually the most active between the hours of 10 a. m. and 2 p. m.

The swaying of the grass and grain stems in the wind appears to be a hindrance to them in alighting and ovipositing, while a sudden mountain gust is apt to put an abrupt end to all efforts for the balance of the day. Sometimes on a still, sunny day they will

spend much of the time quietly on the stem, while again, under apparently the same conditions, they are constantly in motion, flying and hovering a long time before alighting.

The female evidently selects the particular stem in which to oviposit, and once she has chosen and settled, she seldom changes to another stalk, although she may halt at several places on a single stem and attempt oviposition at each point. Occasionally, after a hasty examination, she may again take to wing and make another choice. Repeated observations seem to have established the fact that one of the chief requisites of a proper stem is that it shall not yet have put forth a head. In all the instances where oviposition has been observed, the female has never been known to choose a stem with a head.

When she has made her selection of a suitable stem, the female usually alights about halfway up and runs briskly to the upper end, halting almost imperceptibly every few steps. The gait of an ascending fly is so characteristic that it determines with much certainty whether the individual is a female intent on oviposition.

Arriving at the apex of the stem, after a careful survey of its condition, she frequently preens herself carefully. She then descends, exaggerating slightly the hesitating step by which she had ascended. The antennæ are held in front of the head parallel with the stem as she moves, and she occasionally touches the surface of the stem with their tips. There is none of the rapid antennal vibration so common among the smaller chalcids and many other Hymenoptera. She gives no evidence of being in search of any particular point, but goes straight down the stem.

When satisfied with the location she halts abruptly, usually an inch or less above the second node from the top of the stem, slowly arches her abdomen and, clasping her hind pair of feet around the stem as far as they will reach, begins to drive the saws into the hard outer tissue. Figure 13 shows the attitude taken by females at this time, though they usually face downward. These saws are slightly curved, double, very thin, with serrated edges. (Fig. 14.) They are used to split the outer coating of the stem rather than to cut it, and they make so opening so small that it is almost impossible to find the scar after the wound has healed. These saws are gradually forced into the stem, the operation occupying a minute or more. In the field the female always heads downward during oviposition and the curve of the saw blades brings the tips, when fully inserted, in a line parallel with the axis of the stem. These are frequently partly withdrawn and their direction slightly changed. When the stem is in proper condition the saws are thrust in several times, as far as they will go, then withdrawn, the dorsal part of the pygidium being used as a

falcatus to subject them. They are inserted again, this time often with a twisting motion as if trying to enlarge the opening. They are finally forced in as far as possible, as is evidenced by the tenseness of the rear legs straining at the stem, and are held in this position for half a minute or more.

When busy with oviposition the sawfly seem oblivious to whatever is going on around them, and the writer has repeatedly watched, through a half-inch triplet, the female manipulating her saws. It is impossible to determine under the closest scrutiny just when the egg is passed into the stem. It is probably at the time when the female stands motionless, after the saws have been drawn in to their full length.

The function of these saws appears to be twofold. At Pinto, Utah, in June, 1912, the writer found that the eggs were invariably placed in a cell hollowed in the solid parenchyma of the core of *Elymus condensatus*, this cell being a little larger than the egg. Besides piercing the stem, the saws are also of use in excavating this egg cell, in case such a cell is needed. At Kimballs near Salt Lake City, in

FIGURE 14.—Saw of western grass-stem sawfly highly magnified

the same grass, the eggs were nearly always placed in the hollow part of the stem, lying free in the central cavity.

Normally but one egg is placed in each stem. However, no attention is paid to previous oviposition, and as many as five eggs have been taken from a single stem. As is stated elsewhere, only one of the larvae can possibly survive until fall.

The date of oviposition (fig. 15) varies with the latitude and the altitude. At Pinto, Utah, on the edge of the desert country and with a low altitude, newly hatched larvae were found June 14, 1912, while at Kimballs, 240 miles north of Pinto and with an altitude of 7,000 feet, oviposition was beginning during the first week of July in the same year.

Criddle states that in Canada most of the eggs are deposited in June. The date of oviposition in the Dakotas and in Minnesota is unknown.

KEY TO NORTH AMERICAN SPECIES OF CEPHUS

Through the courtesy of S. A. Rohwer, a key for the determination of the adults of known species of the genus Cephus occurring in North America is here presented.

Adults had trunk dark brown or black, sometimes piceous, antennæ black; apical tergite and venter black; face and scutellum black (face of male with yellow spots) ..... *pygmæus* Linnæus[a]

Scape in greater part and coxæ yellow; mesepisternum with the upper angle yellow; apical tergite and usually the lateral lobe of penultimate tergite mostly yellow; face and scutellum of female usually black and sometimes with yellow spots..... *cinctus* Norton

NATURAL CONTROL

Under normal conditions, when *Cephus* is exclusively or chiefly on grass stems, its larvae were attacked by two or more species of parasites that destroyed numbers of them and kept those within reasonable bounds. Although the fly has begun to change its habits and to subsist to a certain extent on wheat and other small grains, these parasites apparently are still confining their attacks largely to those larvae that they find in grass stems. The proportion of larvae parasitized in wheat stems, however, seems to be steadily increasing, and counts in 1927 showed 18 to 30 per cent of such larvae parasitized.

FIGURE 15.—Life-history diagram of the western grass-stem sawfly

The most common parasite found everywhere in the grasses is *Pleurotropis utahensis* Cwfd., a beautiful little bronze-green chalcid that was reared by the writer from numerous larvae taken near Salt Lake City, Utah, from hibernation cells of the sawfly. This species appears to kill the larva only after the latter has formed its hibernation cell. It is gregarious and seldom or never attacks its host singly. As many as 12 of its larvae have been taken from a single cell, but 5 or 6 is a more common number. These larvae are white and are from 2.5 to 3.5 millimeters in length. They are somewhat active and travel slowly about the cell when mature. They are often found crowded together in one end of the cell, but when disturbed will scatter about the chamber. (Fig. 16.)

Although this species is widely distributed and propagates in numbers it appears to destroy only a small percentage, possibly 10 per cent, of the *Cephus* larvae in the native grasses of Utah. In Bottineau County, N. Dak., it attacks the sawfly very freely in Brome and timothy, and in some localities has killed more than 50 per cent

[a] *Cephus pygmæus* is not known to occur anywhere west of Pennsylvania but its habits are similar to those of *C. cinctus*.

of the Cephus larvae. Isobrachium and one other parasitic species are so numerous in these roadside grasses that it would seem poor policy to recommend the cutting of the grasses in midsummer as a measure of sawfly control.

A braconid, *Microbracon cephi*, described by A. B. Gahan[1] also attacks the larvae in grass stems, kills them before maturity, and spins a gray parchmentlike cocoon within the gallery, generally near its lower end. This cocoon is truncate at both ends, its flaklike extremities completely filling the bore. The adult escapes by biting an opening through the stem in the vicinity of the cocoon.

FIGURE 10.—Larvae of [illegible] in grass stems, a number of the stems split open to show the larvae

ARTIFICIAL CONTROL

From the foregoing sketch of the life history of the western grass-stem sawfly it seems obvious that this pest will have to be attacked while it is in the larval stage. The egg and adult stages are both brief and are clearly beyond the reach of control measures of any sort. For nearly 11 months the insect exists as a helpless larva, protected only by the grass or grain stem within which it lives. If this stem could be destroyed, the larva within would perish.

The first remedy that occurs to the farmer or the student of field conditions is the burning of the stubble in the fall or spring. It would seem a very simple matter to set fire to the stubble and destroy at least the majority of the sawfly larvae that are hibernating in it. But when one begins to examine the infested fields it is found that the insect has cut inhabited stems at the ground level or below, so it is often necessary to brush away the earth in order to find the stubs containing the larvae. So little heat is generated when stubble is burned that these subterranean stems could not possibly be harmed by the quick passage of the flames.

In 1907 Norman Criddle, in Manitoba, wishing to make a thorough test of this remedy, spread a layer of straw several inches deep over an infested spot in a wheatfield and set the straw on fire. More heat was produced than stubble alone could possibly make, the surface of the ground being too warm for the hand after the fire had died down. Even after this severe treatment it was found that, as far as could be learned by a minute search, not a single larva had suffered. They had simply retreated to the lower end of the hibernation cell and kept cool.

[1] GAHAN, A. B. [illegible] OF A NEW HYMENOPTEROUS PARASITE [illegible]. Ent. Soc. Wash. Proc. 20 (1): 18-19. 1918.

Another fact must be noted in this connection. When a field has been damaged seriously by the sawfly, the stubble remaining to feed a running fire is of necessity more scanty than in an uninjured field and consequently it would be exceedingly difficult to burn such a field under common conditions.

In Utah the bunch grass, *Elymus condensatus*, is much infested by this same fly and frequently is burned by fires that sweep the mountain sides. This Elymus forms dense sods, with stems often more than 3 feet in length, and the heat from its combustion is great. The writer has examined a large series of burned sods and has seldom discovered any injury to the larvae from the fire.

Some exceptions are to be noted. A few cases are on record where, because of favoring weather in the semiarid region, the wheat made an unusual growth of straw, and probably because of this rank growth the Cephus larvae cut the stems higher than usual, leaving stubs that projected an inch or two above soil level. To lessen the quantity of straw to be handled at threshing time it is the practice to raise the reaper cutter bar, leaving long stubble in the field. When such a field is burned over later the fire runs readily, and a large majority of the larvae are destroyed before they can retreat to the lower end of the hibernation cell. But such fortunate conditions seldom occur. As a rule, burning the stubble as a control measure is futile.

One method of control that has been highly recommended consists in plowing the infested stubble under in the fall or early spring before the flies have emerged. When properly done this method has been quite successful in preventing their emergence. But the manner of plowing is important. The furrow slice should be turned completely over in order that the top of the stubble shall come in contact with the firm bottom of the plow cut. Where this is done the flies are unable to make their way out of the stubs to reach the surface of the soil. The difficulty with this method lies in the fact that, unless great care is exercised, the furrow slice will not be wholly inverted and as a result the infested stubs will lie horizontally in the loose soil, thus allowing flies to emerge without much difficulty. There are almost always some cracks and openings in the furrow slice that permit easy egress. Because of these drawbacks less emphasis is now being placed on this method of control than formerly.

In the fall of 1916 the writer buried four lots of infested stubble in different depths of earth sifted and compacted by jarring. These were buried, one at 3 inches, one at 4, and two at 6 inches, in glass jars, 10 stubs in each of the first two, 20 in the other two. On August 6, 1917, these cages were examined, with results as follows:

Under 3 inches of earth all had emerged as adults.

Under 4 inches 1 larva had died, but all others had emerged as adults.

Under 6 inches 1 adult and 6 larvae had died in the cell; all others had emerged as adults, except 2 active living larvae which remained in the cell.

Under 6 inches 7 larvae had died in the cell; all others had emerged as adults.

Lumpy soil in the field might make it easier or harder for adults to emerge than fine soil in a jar, and this point is difficult to determine.

Cultural conditions in North Dakota are not favorable for burying the stubble by plowing. Spring wheat is followed in many cases by winter rye which is disked into the wheat stubble after harvest. This procedure leaves all the infested stems of wheat on the surface, and nothing could be more favorable for the escape of the adult flies in the following spring. The wheat stubble seems to be necessary in this region to hold the winter snow for the protection of the young rye, hence the farmers seldom or never plow the stubble under before sowing the rye.

Without any doubt grainfields in North Dakota and Canada are invaded regularly by sawflies that issue from grass growing along their borders. Although it might seem possible to decrease the numbers of the fly by mowing roadside and fence-row grasses in July, thus destroying the larvae always present in the stems of these grasses, careful study has proved that a large percentage of such larvae are parasitized, and therefore it would seem unwise to take steps that might diminish the number of parasites.

Previous to 1919 it had been stated with much confidence that durum wheat was nearly immune from the attacks of the sawfly. On the strength of these statements authorities were inclined to recommend the barring of Fife and Marquis and the softer-stemmed wheats from the areas of North Dakota and western Canada in the hope that by this means the work of the sawfly might be checked and a more certain harvest assured. It was readily seen that an immune wheat would solve the problem of the sawfly.

Observations made by the writer in August, 1919, and referred to on page 6, included in their scope an inquiry into the question as to the alleged immunity of durum wheat. Farm work was too far along at the date of this visit to permit of effective field work to settle the matter definitely, but several farmers informed the writer that durum had suffered severely that year, although not so much as either Fife or Marquis wheat, and the agreement on this point was general.

The apparent resistance of durum may vary from year to year and is possibly based on the relation of the date of the appearance of the adult Cephus to the rapidity of growth of the young grain. The stem of the durum wheat is more dense and unyielding than that of other varieties, and if a warm rainy spring should hasten its growth it might prevent the sawfly from placing many eggs. A number of unknown factors enter into this problem that hinder its complete solution at present.

Where practicable, rotation of crops is recommended, and especially the sowing of winter rye. This grain ripens early and therefore can be cut before the sawfly larva reaches the lower end of the stem. It joints early in the season and thus proves attractive for oviposition when the flies appear. In North Dakota rye is very hardy, and nearly a third of the rye crop of the United States has been grown in that State.

Farm practice that includes proper rotation, following small grain crops with some crop that does not serve as a host plant, should prove more or less effective in reducing the damage from the attacks of these flies. Oats and flax are entirely free from attack by Cephus.

SUMMARY

The western grass-stem sawfly (*Cephus cinctus* Norton) is a wasp-like insect that originally attacked no cultivated crop but inhabited the large-stemmed native grasses of the northern Great Plains. When such grasses began to be largely supplanted by wheat and other small grains, however, the insect attacked these and has gradually become a pest of considerable importance.

Although this species is found in most of the Western States from central Michigan and eastern Missouri westward to the Pacific it has thus far been injurious principally in the great spring-wheat districts of North Dakota, Montana, and the neighboring Provinces in Canada. Of the cultivated grains it prefers wheat but has been found feeding on rye, spelt, and barley to some extent.

The egg is laid within the stem of the host plant by means of a sawlike ovipositor with which the adult insect easily penetrates the tough outer wall of the stems. Hatching occurs in about one week, and by means of its powerful jaws the young larva feeds on the interior of the stem, moving up and down in its gallery until about the time the wheat begins to ripen. It then gnaws a groove on the inside of the straw completely around the circumference of it and at about the level of the soil surface. Afterwards, descending slightly lower in the underground stem, it fills the gallery above itself, and just below the groove, with a plug of frass, thus closing the upper end of the stub that is to be left in the ground after the upper stalk has been broken away. In this stub the larva spins a delicate silken tube and hibernates. Where more than one larva inhabits a stem the stronger insect devours the others, so only one individual remains at hibernating time. In the spring the larva again becomes active but finally changes to a pupa and this, a short time thereafter, changes to an adult sawfly, which presently forces its way out of the stub.

The principal injury occurs to the grain not so much from the quantity of food that the insect removes from the plant as from the breaking of the straw before or at harvest time as a result of the groove cut by the insect, which causes much of the grain to fall to the ground or lodge so that it can be harvested only with great difficulty.

When inhabiting the grasses this sawfly is largely controlled by its parasitic enemies, but in wheat and other small grains this beneficent agency seldom functions.

Several partially effective cultural methods have been tried in attempts to control the pest, and among those that show some promise of success is plowing the infested stubble under in such a manner that the entire slice is inverted, thus preventing the adults from emerging. A rotation from wheat to flax, oats, or other crops which are not affected by the sawfly has been found advantageous but no specific remedy for this insect is yet known. Under ordinary conditions the burning of the infested stubble in the fall or spring does not seem to heat the ground sufficiently to kill the larvae in the underground stems.

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